WOODS HOLE OCEANOGRAPHIC INSTITUTION

Reference No. 60-21

The Development of Fluid Model Analogues of Atmospheric Circulations

by

Allan J. Faller

Quarterly Status Report No. 5

Jan. 1 - Mar. 31, 1960

WOODS HOLE, MASSACHUSETTS

THE WOODS HOLE OCEANOGRAPHIC INSTITUTION

HYDRODYNAMICS LABORATORY

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The Development of Fluid Model Analogues of Atmospheric Circulations

Contract No. AF 19(604)-4982

Alan J. Faller, Senior Investigator

W.H.O.I. Reference No. 60-21

Objectives:

1. Perform comparative studies of the similarities and differences of the results of laboratory experiments and theoretical investigations of models of the large-scale atmospheric circulations.

2. Conduct a study of the effects of variations of such factors as static stability, friction and heating on the behaviour of laboratory models of atmospheric circulations.

Submitted to the Geophysics Research Directorate, Air Force Cambridge Research Center, Air Research and Development Command. This report is intended only for the internal management uses of the contractor and the Air Force.

1) General

During this quarter experimental studies of frictional boundary layer circulations with the use of the large rotating tank have made rapid progress with the discovery of the existence of a critical Reynolds number for the flow in an Ekman boundary layer. The successful demonstration of the organized formation of roll vortices when boundary layers in the rotating system become unstable has lead to considerable speculation as to the possibility of similar phenomenon in the atmosphere and has given increased significance to the experimental studies.

Modifications of the thermal convection apparatus have continued in an attempt to perfect the apparatus for carefully controlled experiments. Mr. Hjalmar Nelson worked for the latter two months of the period, and has nearly completed the revised apparatus.

2) Thermal convection between two heated plates

For convection experiments using air as a fluid, precise thermal control of the boundaries is of paramount importance. Because of the low heat capacity of the air compared to solid materials of which the boundary must be composed, small departures in the boundary temperatures from the prescribed values become important. This is especially true for the experiment contemplated here because of the requirement of horizontal homogeneity in the stability problem.

To provide homogeneous temperatures for the upper and lower plates of the convection chamber two sets of heating elements have been purchased. The first consists of a closely wound wire ($\frac{1}{4}$" spacing) imbedded in a rubber matt. These elements have been glued to the outside faces of the upper and lower aluminum plates. This construction replaces the air circulation system which is used now to maintain the environmental temperature at the same value as that of the plates by a thermistor controlled regulating system. A pair of transparent glass plates each with a conducting film on the surface have been purchased for experiments in which the forms of convection will be viewed visually and photographed.

Control of the side boundary conditions has been improved by replacing the "Styrafoam" walls with a laminated wall consisting of vertical sheets of copper of thickness .001" and sheets of "Styrafoam" 1/3" thick. This proportion of materials provides a wall with a thermal diffusivity approximately equal to that of air so that the vertical temperature distribution in the wall due to the steady rise of temperature will closely approximate that in the air.

Other improvements have been made in the apparatus such as a revision of the air circulation system and replacement of the resistance wires with wires of precisely uniform length so that the calibration of all elements will be nearly identical.

3) <u>Studies of frictional boundary layer circulations</u>

The first successful studies with the use of the 4-meter rotating tank have shown that there is a critical Reynolds number for the boundary layer flow. The dimension used in the Reynolds number in this case is the vertical thickness of the boundary layer. The experimental arrangement is that described in Q.S.R. No. 3. Water is pumped from the center of the tank and is distributed as a source around the rim. The radial flow from rim to center takes place in a shallow viscous boundary layer at the bottom of the fluid and the flow far above the boundary layer is essentially in geostrophic or gradient balance for the range of parameters employed.

Figures 1 and 2 are photographs for somewhat different conditions and show the transformation from laminar flow to rolls and then to turbulence at different radii of the tank. The pattern of flow is made observable by introducing crystals of potassium permanganate into the boundary layer near the rim. In the absence of turbulence, the zonal speeds of flow would be approximately given by the formula $vr = C$ so that the basic current is inversely proportional to radius. The variations of the nature of the boundary layer flow with radius, therefore, correspond to variations of the basic flow field. The wave length of the rolls of the primary instability appears to be to a first approximation a constant multiple (3.5) of the depth of the Ekman boundary layer, $D_{Ek} = \pi \left(\frac{\nu}{\Omega}\right)^{1/2}$. Figures 1 and 2 correspond to higher and lower values of the rotation rate and demonstrate the dependence of wave length upon boundary layer thickness.

A systematic study will be made to determine precisely the critical value of the Reynolds number for this flow and to study the modification of the boundary layer profile and the variations of the critical Reynolds number as the flow is made to depart from geostrophic balance and from the Ekman boundary layer profile.

4) <u>Administrative</u>

Mr. Hjalmar Nelson, Jr. returned to work February 1 after a study period at Northeastern University.

Financial Statement:

Expenditures through March 31, 1960.......... $ 3,301

Balance of funds available to Dec. 31, 1960... $18,228

Figure 1

A demonstration of the instability of Ekman boundary layer flow and the formation of roll vorticies at a critical speed of flow.

Rotation rate Ω = .140 sec^{-1}

Flow rate S = 670 cm^3/sec

Note that the wave length of the disturbances is smaller than for those of figure 2 corresponding to a higher rotation rate in figure 1. Also, the critical radius of instability is somewhat less than in figure 2 corresponding to a smaller value of the forced flow.

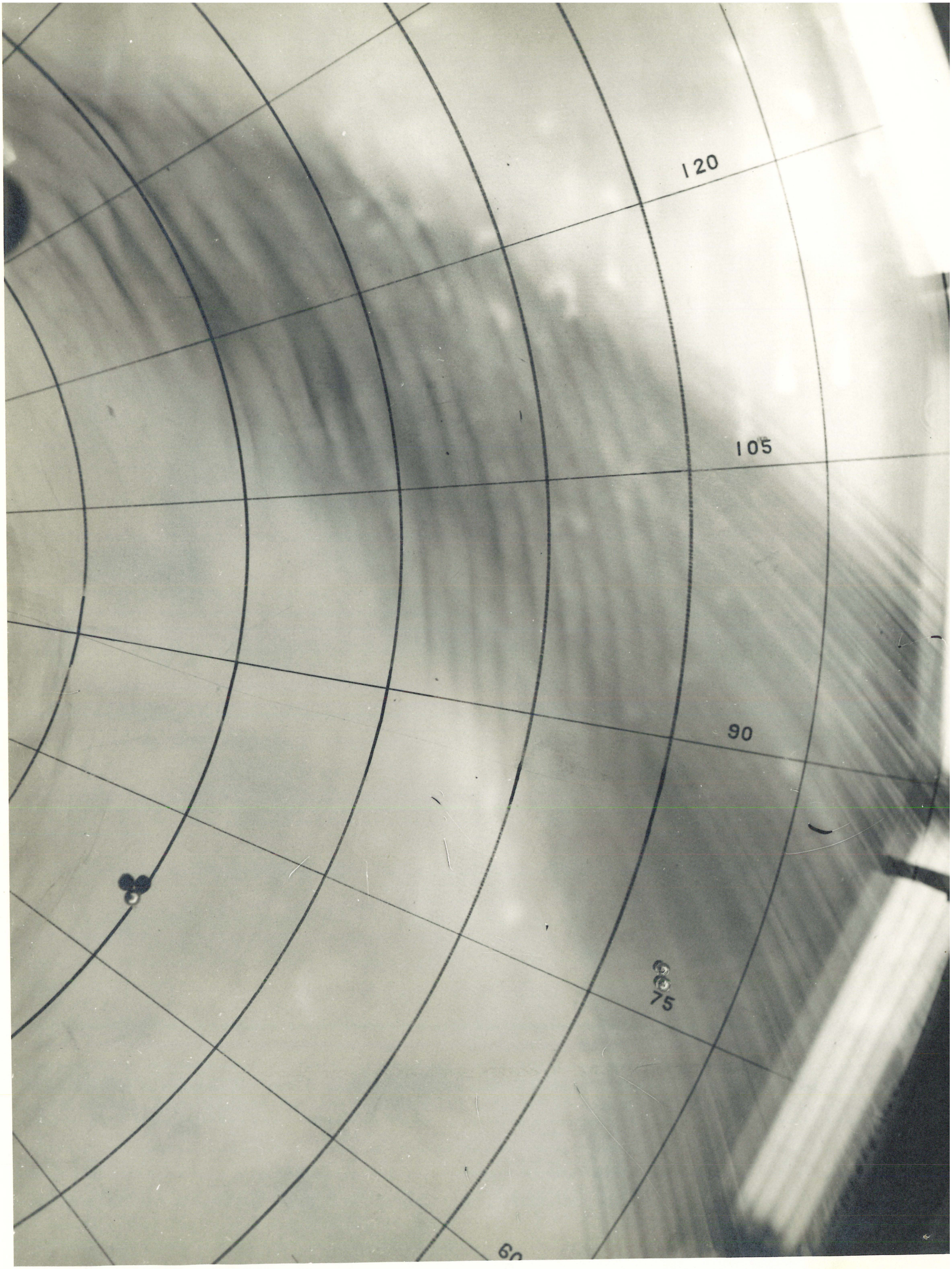
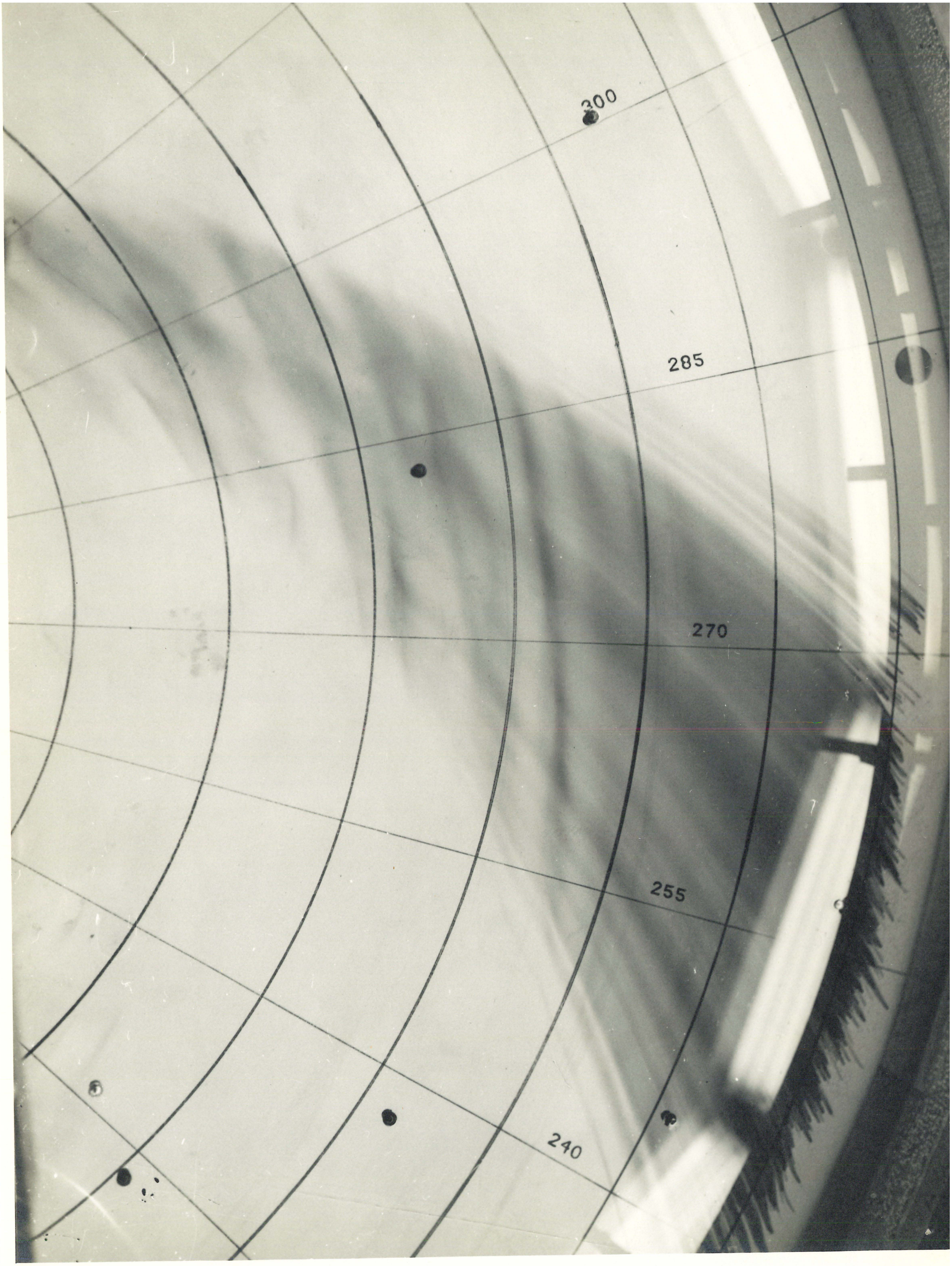

120
105
90
75
60

Figure 2

A demonstration of the instability of Ekman boundary layer flow and the formation of roll vorticies at a critical speed of flow.

Rotation rate Ω = .036 sec^{-1}

Flow rate S = 760 cm^3/sec.



300
285
270
255
240